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THE EFFICACY OF LEAD ARSENATE IN CONTROLLING THE CODLING MOTH

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The investigator who undertakes an orchard spraying experiment for the purpose of determining the value of one or more elements in the spraying method of controlling the codling moth, *Carpocapsa pomonella* (Linn.), is confronted by a large number of unknown and uncontrollable factors which influence in various ways and degrees the results of his experiment. Conclusions arrived at under such conditions of experimentation are likely to be lacking in explicitness and accuracy, and they may sometimes be wholly erroneous. It is a well known fact that the vast literature on codling moth spraying is replete with contradictory experimental data, and discordant opinions and beliefs. A number of points of primary importance regarding this method of control have continued to remain largely in the realm of assumption and theory every since spraying was first employed in codling moth control nearly fifty years ago. Spraying tests have been confined almost without exception to orchard conditions.

While assisting in some orchard experiments during the summer of 1917 to determine the relative merits of spraying and dusting with lead arsenate as a means of controlling this pest, I was impressed by the fact that so many variable factors were encountered as to render the resultant data of very doubtful value. Similar experiences met with in subsequent investigations and a study of the investigations of other entomologists emphasized the desirability of more accurate experimentation than could be accomplished under orchard conditions. It was during the late summer of 1920 that the idea was conceived of performing experiments with freshly hatched codling moth larvae in the laboratory. The work started that year was continued in a limited way in 1921, while fairly extensive studies were made in 1923 and 1924.

The earlier work was conducted at the Idaho Experiment Station; that of 1923 was performed in the laboratories of the Golden State Milk Products Company of San Francisco, and that of 1924 at the University of California. This paper* is based chiefly on the investigations of 1924.

Probably no other insect in the history of American horticulture has been the subject of more discussion and experimentation than the codling moth. The literature relating to it is very extensive. In 1888, L. O. Howard[9]† stated that the Office of Entomologist of the United States Department of Agriculture had proposed compiling a list of American writings on the codling moth, "but soon found that it would consume altogether more space than could be allowed." It is probable that the literature has increased several fold since that year.

Much of the published matter on the use of arsenical compounds in spraying for codling moth is perplexing to the reviewer. It is sometimes impossible to determine whether the statements of a writer are based on his own observations and experiments or on those of other persons, or whether they are based merely on assumptions. There is much contradictory and inconsistent data, explanations for which are either obscure or entirely lacking.

In order that the reader who is not especially familiar with the subject may have a better understanding of the significance of the research reported herein, a brief review of the history of the spraying method of control is given. This review is of necessity very fragmentary. Only a few references out of hundreds have been cited.

BRIEF HISTORICAL REVIEW OF CODLING MOTH SPRAYING

Early Experiments with Arsenical Sprays

The use of arsenical compounds in codling moth control originated in 1878 when it was discovered that the practice of spraying apple trees with Paris green to destroy the spring canker worm not only controlled that pest but also reduced the injury from codling moth.[1] Experiments on the value of this treatment, made by Cook of Michigan in 1880, indicated that it was highly effective.[2] Other experiments reported in 1886 by Forbes of Illinois[3] and Goff of New York[4] confirmed the findings

* Acknowledgment is gratefully made for suggestions and assistance given by members of the staff of the Division of Entomology and Parasitology of the University of California at Berkeley and to Mr. C. E. Gray, president of the Golden State Milk Products Company, for permission to use the photographs shown in figures 7, 8, 12 and the lower part of figure 2, which were made by me in the laboratories of that company.

† Superior figures refer to bibliography at the close of this paper.

of Cook. Since then practically all investigations of control have dealt either directly or indirectly with the arsenical method. Soon after 1890 all authorities seem to have reached the conclusion that spraying was so efficacious that the old methods of control, including banding of trees and destroying wormy apples, were no longer worth while. Since the establishment of the State Agricultural Experiment Stations in 1888, spraying experiments have been carried on more or less continuously in every important apple-producing state in the United States. Something over two hundred state and federal bulletins and major papers in serial publications, containing original reports of such experiments, have appeared during the past twenty-five years.

Potency of the Spraying Method

After eight years of experimentation in spraying with Paris green, Cook, in 1888, came to the conclusion that if all apples of a tree "received the poison" no injury from codling moth would result.[8] Wormy apples, he believed, could be attributed only to "lack of thoroughness" in applying the spray. In general agreement with Cook, later authorities have inclined to the belief that if every calyx and every apple were thoroughly treated with arsenical spray, practically complete destruction of codling moth larvae would be accomplished. Some writers have been very emphatic in statements to this effect.

Instances of unsatisfactory control have been attributed chiefly to two factors: first, failure to spray at the most suitable time or times during the season and, second, lack of thoroughness in applying the spray. The object of nearly all codling moth investigations of the past quarter century has been to obtain more accurate information on the "timing" of spray applications, and on ways and means of securing greater thoroughness. The former has dealt with life history studies of the insect while the latter has been concerned chiefly with spraying machinery and equipment.

Spray Applications

Spray applications may be classified in general as of two types, the calyx spray and the cover sprays. The first refers to spraying just after the petals of apple blossoms have fallen. The object of this application is to place a quantity of poison in the calyx cavity of the developing fruit before the cavity becomes closed by the infolding of the sepals. The cover sprays are those that are applied after the calyx application, the purpose being to place a covering of poison over the surface of the growing apple.

Number of Spray Applications

Forbes[6] and Cook[8] early arrived at the conclusion that only the calyx spray and the cover sprays applied soon after the calyx spray were of especial value. This position was strongly supported by Card[31] and Slingerland.[32] On the contrary some contemporary authorities, including Lake,[12] Washburn,[27] and Cordley,[30,41] regarded the calyx spray of little value and emphasized the importance of the later cover sprays. In 1900 Aldrich[36] reported experiments which indicated that the calyx application was over five and one-half times as effective as the cover sprays. Simpson[40] and Gillette[39] reported that eighty per cent of the first brood larvae entered at the calyx. Similar evidence was presented about that time by a number of other investigators and, as a result, there developed a renewed interest in what later became known as the "one-spray method" of codling moth control, or control by the calyx spray only.

The numerous and extensive investigations that were carried on during the period from about 1905 to 1915 centered largely around the one-spray method of control. Considerable data was published indicating that the calyx spray was all-sufficient. It is of particular interest to note that Gillette,[46] Weldon,[47] and Melander[48] reported evidence from the western states which tended to show that the greater the number of sprays applied, the less effective was the control. Melander gathered data from upwards of one hundred apple orchards in Oregon and Washington for the years 1909 and 1910, which showed approximately one per cent wormy apples where the calyx spray only was applied, four and one-half per cent where the calyx and one cover spray were applied, four and one-half per cent for the calyx and two cover sprays, and eight per cent where the calyx and four or more cover sprays were applied. Quaintance,[49] after referring to eleven experiments in eight different states, remarked that "the results of the one-spray method are on the whole excellent and fairly uniform."

Timing of Spray Applications

The rise and subsidence of the one-spray method constitutes an interesting chapter in the annals of codling moth control. There were many marked cases of failure but proponents of the method contended that unsatisfactory control was due to the spray not being properly applied. By about the year 1915, however, nearly all authorities seem to have reached the conclusion that the pest could not be satisfactorily controlled by means of the calyx spray alone, excepting, perhaps, in

restricted parts of the country where, because of peculiar climatic conditions or other factors, the codling moth had failed to become abundant or materially destructive. In the state of Washington where the adequacy of the one-spray method was vigorously defended for several years, and in most other western states, the calyx spray and four cover sprays finally became the accepted recommendation for control; while in parts of Arkansas, New Mexico, Colorado and California, accentuated conditions of infestation have led to the application of from five to ten cover sprays during the summer.

Attention turned more and more to the belief that incorrect timing of cover sprays, rather than deficiencies in applying the calyx spray, was largely responsible for unsatisfactory control. Cordley,[30] who was among the first to take this point of view, expressed the belief that applying a spray "a few days too early or too late may make all the difference between success and failure," and Childs[51] stated that spraying ten or twelve days before egg-hatching would mean "in ordinary seasons of infestation the difference between complete control as against one-half or even less control." Similar beliefs have been expressed by many other students of codling moth control and efforts at the present time are chiefly directed toward improving the effectiveness of spraying through more accurate timing of spray applications.

Thoroughness in Applying Spray

While thoroughness in spraying has always been emphasized, it especially has been the subject of experimentation and extensive discussion during the past ten or fifteen years. The agitation regarding thoroughness has brought forth various kinds of spray nozzles and high-pressured spraying machines capable of producing from three hundred to five hundred pounds pressure. Some authorities have contended that the spray gun or some particular nozzle is especially effective in accomplishing thoroughness and controlling the codling moth while other authorities have presented equally convincing evidence to the contrary. The relative merits of the spray rod and the spray gun in applying the calyx spray and cover sprays, and the relative merits of the disc nozzle and bordeaux nozzle in the calyx application, are points on which there is much confusion of opinion and experimental data. During the past few years the majority of recommendations have called for high pressure, two hundred and fifty pounds or more, but a good many experiments have been reported which indicate that equally good or better control may be obtained by applying spray at pressures of two hundred pounds or less.

The subject of thoroughness involves the question of what kind of spray coverage is most effective. Forbes[6] seems to have been the first to suggest the mist type of coverage. It appears that most authorities have believed this coverage to be the most effective of any. Spray spreaders were used in codling moth control by Klee[7] as early as 1887. They have been experimented with since then by many investigators but only during the past few years has the film type of coverage, obtained by the use of spreaders, come into prominence.

Kind and Quantity of Poison

Paris green was the principal poison used in spraying for codling moth during the period from 1880 to about 1905. Lead arsenate was employed as early as 1895[42] but the first experiments of consequence were made in 1902. It has been used almost exclusively during the past fifteen years.

The matter of poison concentration in sprays has received comparatively little attention. The prevailing belief among authorities has been that the effectiveness of the spray depends not so much upon the quantity of poison on the apple as upon the thoroughness with which the apple is covered with the poison. Melander,[48] in reviewing methods of codling moth control in the Pacific Northwest, remarked that "experimental tests have shown that the strength of the spray is immaterial." Weldon[46] collected data from orchards in Colorado in 1909 and found that better control was obtained with lower concentrations. Melander later expressed the belief that if the apple is heavily coated with lead arsenate, the newly hatched larva finds the skin distasteful and rejects it.[50] Lovett[54] and Childs and Lovett[56] inclined toward the opinion that lead arsenate in concentration of two pounds to one hundred gallons of water is eight times the theoretical strength required to control the codling moth. At present there seems to be general agreement on the recommendation which has prevailed for several years, that nothing is gained by using lead arsenate in greater concentration than two pounds to one hundred gallons of water.

Present Status of Spraying

Notwithstanding that great advances have been made in the perfecting of arsenical compounds and spraying machinery, and in knowledge of the life history of the codling moth, control of the pest in some parts of the country seems to be no more satisfactory now than it was ten or twenty years ago. A careful perusal of horticultural and entomological literature in the Pacific Northwest discloses substantial

evidence that the percentage of apples damaged by the codling moth in that region during the period from 1919 to 1924 inclusive, was fully as great as during any previous equal period. In 1919 Melander, who had been continuously interested in codling moth control in the State of Washington for upwards of twenty years, stated that "undoubtedly the codling moth has been increasing in destructiveness during the last few years."[52] The Grand Valley district of western Colorado affords a striking example of the failure of spray-methods to keep pace with the increasing codling moth hazard.[57]

The spray treatment is not nearly as dependable as is desired. One year it may prove very effective in a given district but another year it may give unsatisfactory control, or, in one orchard it may be effective and in an adjoining orchard very ineffective. Such variations in results have been attributed principally to differences in the timing and thoroughness of spray applications. In general, however, there is a wide gap between the degree of control attainable under orchard conditions and the one hundred per cent control that almost all spray authorities have assumed lead arsenate capable of giving. It seems quite evident that there are important factors bearing on the efficacy of lead arsenate in controlling the codling moth, which have not yet been ascertained.

STUDIES WITH FRESHLY HATCHED CODLING MOTH LARVAE

Methods and Technique

A special effort was made to conduct the different experiments under uniform conditions and, so far as possible, to eliminate such variable factors as might contribute to non-comparability and error in the results. After some experience it was found necessary to outline in detail each separate manipulation. Even with very careful attention to methods and technique, the variation in the results of repeated tests was much greater than was expected or desired. Some of the more important points that were followed in performing the various experiments are briefly outlined in following paragraphs:

Securing freshly hatched larvae.—By placing burlap bands around the trunks of apple trees badly infested with codling moth, thousands of mature larvae were captured. The larvae were placed in fruit jars containing strips of corrugated strawboard in which pupation took place. The moths were allowed to emerge in a cage covered with cheesecloth. From this they were transferred to battery jars. A

covering of wet sand about one-half inch thick had been previously placed in the bottom of each jar. Sections of glass on which the moths might rest and oviposit were sometimes placed in the jars. The jars were wrapped in four thicknesses of black cheesecloth and kept in a room where a temperature of approximately 80° F. was automatically maintained. The black cloth over the jars caused the moths to oviposit during the day. After some experience with the moths it was found possible to secure from a few hundred to over a thousand eggs in each jar within a period of three days (fig. 1). At the end of the third day, and sooner in some cases, the moths were released and the wing scales, fecal material and sand washed from the jars by using an abundance of tap water. If the jars were not thoroughly washed out

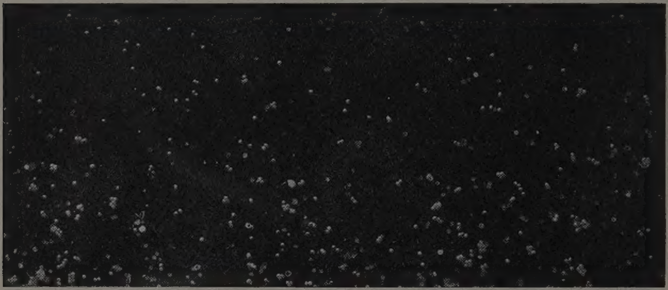

Fig. 1. A section of glass after removal from a battery jar containing moths. Approximately six hundred eggs may be counted on this section.

it was found that some larvae swallowed particles of the loose substances. Rooms in which high or low temperatures could be automatically maintained were accessible for hastening or retarding as desired the processes of transformation, egg-laying and incubation.

Preparation of apples.—Only apples from unsprayed trees were used in the studies. In collecting the apples, each was grasped by the thumb and fore finger while the stem was clipped off close to the fruit spur. All handling thereafter was done by holding the stems with forceps. Touching the apples with the hands affected the surfaces in such manner as to influence the spray covering subsequently applied. In the laboratory the calyx lobes were clipped off if they protruded and the calyx cavities filled with shellac. It was found important that the shellac be even with the surrounding surface of the apple because any ridge or protuberance materially aided the larvae in effecting injuries. A piece of cotton thread was tied to the stem of each apple. The transverse and vertical diameters were then measured and recorded.

Technique in spraying apples.—In the work of 1920 and 1921 an atomizer operated by blowing the breath through it was used for applying the spray. It was later discovered, however, that the carbon dioxide of the breath caused a marked increase in the thickness of the film coverage when casein-lime was employed as a spreader; consequently, a rubber bulb type of atomizer was used in the studies subsequent to 1921. The atomizer was kept in constant agitation while

Fig. 2. Upper: several series of apples in the studies of 1924, showing manner in which apples were suspended over vessels of water. Lower: illustration of studies made in the summer of 1923.

applying the spray in order to have the lead arsenate uniformly in suspension. Uniformity of suspension was not satisfactorily maintained in case of the concentrations of eight and sixteen pounds to one hundred gallons.

In applying the spray, each apple was suspended and given a rotating movement. The entire surface was then sprayed uniformly until the desired type of coverage was effected. Except in the case of the mist coverage, the atomizer was first placed near the base of the stem and the basin about the stem filled with spray. This spray was withdrawn

by means of a pipette as soon as spraying of the apple was completed. When casein-lime spreader was used to effect the film coverage, the large drop or drops which formed on the lower surface of the apple were removed by touching that part with blotting paper immediately after spraying. This was done in order to secure more accurate data on the relation of the thickness of the film coverage to protectiveness. After being sprayed the apples were suspended on racks (fig. 2). A vessel of water was placed beneath each apple and in many of the tests a small quantity of tanglefoot was placed on the thread just above the stem. By this means any larvae that fell off of the apples or attempted to crawl up the thread were trapped. Very few were caught in the tanglefoot but many fell off in the water.

Transferring the larvae.—Many factors relating to the transferring of the larvae were found to make for error in the results. There was often much variation in the vigor and size of different larvae, even among those hatching at the same time. Larvae hatching between dawn and about ten o'clock in the morning seemed to be stronger and more likely to produce injuries than those hatching at mid-day or during the afternoon. The first larvae to hatch from a given lot of eggs showed greater vigor than those last to hatch. It also seemed that larvae hatching from eggs whose development had been retarded by being placed in a room with a temperature of about 50° F. were less vigorous than those whose development in the egg had been unchecked. In order to equalize this variation in vitality, the larvae were transferred to the apples in rotation. Five larvae were placed on the first apple, five on the second apple, five on the third, etc., until each apple of a series had five larvae. This was then repeated until a total of twenty-five larvae had been transferred to each apple.

A finely pointed artists' brush, size No. 1, was used for handling the larvae. The brush was kept soft and flexible by moistening it frequently. Considerable care had to be exercised in order to place the larva ventral side down on the apple so that it could make contact with the surface with its legs and spinneret. In case of the spotted coverages an endeavor was made always to place the larvae on the areas between the deposits of poison. Twenty-five larvae to each apple was the standard number used. Special tests were made in which the number ranged from five to two hundred per apple.

Laboratory conditions.—The studies of 1924 were conducted in the northwest room of a building. The apples were exposed to diffused light which entered through large windows on the north and west. The temperature of the room averaged approximately 72° F. but there was considerable variation owing to the fact that the heating plant was

undergoing repair. In the series of tests, numbers 15 to 20 inclusive, shown in table 1, the temperature fell to about 60° F. soon after the larvae had been transferred. This probably was responsible for the much lower percentage of injury caused to the apples of these series. The day temperature in Berkeley, where the tests of 1924 were performed, commonly falls below 60° F. in July and August. This also holds true for San Francisco where the 1923 studies were made. On the whole, the laboratory conditions were not satisfactory as regards temperature.

Types of spray coverages.—When a suspension of lead arsenate in water is applied in finely atomized form to the surface of an apple, the liquid particles tend to collect into droplets. Upon evaporation of the water isolated deposits of the compound remain, resulting in what may be termed a spotted spray coverage. By placing in the spray suspension some substance that sufficiently lowers the surface tension, the

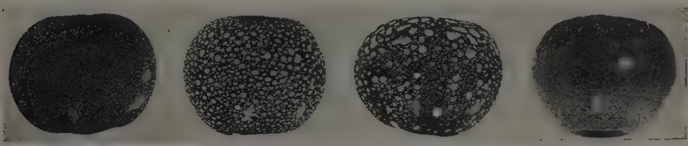

Fig. 3. The four types of spray coverages that may be produced on the surfaces of apples. Left to right: mist coverage, coarse coverage, overspray coverage film coverage.

droplets will coalesce and form a continuous liquid film. Upon evaporation of the water an unbroken film of the compound remains. This has been termed the film spray coverage in this paper. The substance added to the spray for the purpose of producing the film coverage is known as a spreader.

In the studies of 1920 and 1921 tests were made of two coverages; the film coverage and a coverage that, for the most part, consisted of small spots. The results of the tests were so variable that it was found necessary to differentiate among spotted coverages. In subsequent work three types of spotted coverages were distinguished; the mist coverage, the coarse coverage and the overspray coverage. The mist coverage was produced by exposing momentarily the whole surface of the apple to a finely atomized spray. This resulted in a covering of isolated spots ranging in size up to approximately two millimeters in diameter. The coarse coverage was produced by applying the finely atomized spray continuously until the drops that formed on the surface of the apple were as large as would remain in place. The aim was to stop spraying just before any drop became large enough to run down. The overspray

coverage was produced by applying the finely atomized spray in such quantity that large drops collected and ran down more or less irregularly over the apple.

Particular attention is called to the fact that notwithstanding the technical manner in which the spraying was done, there was considerable variation in the character of each type of coverage on different apples. This was especially true of the mist and coarse coverages. Sometimes the spots on the side of an apple were much larger than those on the bottom or top. In some of the tests it was noted that about two-thirds of the surface of an apple was covered fairly evenly with drops of almost maximum size while the remaining surface had scarcely more than a mist coverage. In order to prevent drops from running off, it was necessary to leave some parts improperly covered. Owing to a very slight coating of dust or possibly to some other condition of the surface, larger drops would collect on some apples than on others. On some there was an appreciable tendency for the drops to spread, resulting in spots more or less irregular in outline. This lack of uniformity in coverage was probably responsible for much of the variation in the number of larvae causing injury to apples in different tests.

Materials used.—The lead arsenate used represented two makes: Sherwin-Williams and General Chemical Company. Both were powdered acid lead arsenate ($PbHAsO_4$). The contents of two one-pound commercial cartons were thoroughly mixed together. Analysis showed this to contain 31.2 per cent of arsenic oxide and 0.11 per cent of arsenic oxide in soluble form. The solubility test was made by placing a quantity of the lead arsenate in distilled water at approximately 76° F. for twenty-four hours.

The spreader used for the film coverage consisted of a mixture of casein and calcium hydrate in proportions of twenty-five per cent casein and seventy-five per cent calcium hydrate. This was used at the rate of one pound to one hundred gallons of spray. The casein was a readily soluble form and the calcium hydrate was practically free of carbonates. In all instances distilled water was used and the spray applied within a few minutes after being prepared.

Determination of injury.—Two forms of injury were distinguished: entrances and stings. An entrance corresponds to the term "worm" as commonly used in codling moth writings. It refers to the injury produced by a larva that has burrowed through the skin and into the tissue of the apple without having become poisoned. A sting refers to the injury caused by a larva that has attempted to enter an apple but because of the effects of poisoning or for other causes ceased burrowing after making a slight pit in the skin or, at most, a small excavation in the tissue of the apple.

It was found that in entering the apple the larva generally makes a small excavation under the skin and sometimes spends two or three days apparently feeding in the excavation before starting to burrow toward the center of the apple. The apples, therefore, were left suspended for six days after the larvae had been transferred to them. On the sixth day each apple was submerged in hot nitric acid to dissolve off the arsenic. This treatment removed all frass and excremental

Fig. 4. Left: apples cut into halves showing condition of spray coverages just before submerging in hot nitric acid solution. Right: the same apples after the arsenic had been dissolved off.

material and, in addition, caused a pronounced discoloration at each entrance and sting, which greatly simplified the task of determining injuries (fig. 4).

An incision approximately one-fourth inch deep was made under each injury. Any burrow that extended deeper than this was recorded as an entrance. Injuries of lesser extent were considered stings unless the larvae were found in such stages of development that they doubtless had been alive at the time of dissolving off the arsenic.

It should be especially noted here that a fairly large percentage of the stings recorded in following tables were so slight that they would have escaped notice on the surface of a growing apple. Considerable care had to be exercised in collecting apples from trees in order to avoid the use of any having skin blemishes which would be confused with sting injuries later on in the experiments. Such irregularities would also materially aid the larvae in producing injury.

Determination of arsenic.—A simplified method was employed in determining the amount of arsenic on the apples. A solution of nitric acid was made up, consisting of fifteen parts of arsenic-free, concentrated nitric acid and eighty-five parts of distilled water. A beaker containing a sufficient quantity of this solution in which to submerge the apple was placed over a Bunsen flame and the solution brought to the boiling point. The apple was placed in the beaker and rotated with a glass rod for about one-half minute while the solution boiled strongly. It then was impaled on the glass rod, lifted from the solution and the surface washed with a stream of hot, dilute nitric acid.

Determinations were made of the amount of arsenic on four apples at a time, each group of four apples being from successive series of tests. Sufficient arsenic was present on any four apples to enable determination by titration. The amount of arsenious oxide, expressed in micromilligrams,* was divided by the total area of each four apples. The area was expressed in square centimeters. This gave the average number of micromilligrams of arsenious oxide per square centimeter of apple surface. The surface of each apple was computed by using the average of the transverse and vertical diameters.

LARVAE ON APPLES SPRAYED WITH LEAD ARSENATE

The studies reported in this paper comprise records of over fifteen thousand freshly hatched codling moth larvae. Of this number over twelve thousand were placed directly onto apples, twenty-five being placed onto each of four hundred eighty-three apples. A number of experiments were made with apples hanging naturally on trees in the orchard.

Studies Made in the Laboratory

The results of the most extensive single study are given in detail in table 1. This study included tests of seventeen different combinations of spray coverages and lead arsenate concentrations. The table gives

* One micromilligram equals one-thousandth of a milligram.

TABLE 1

Results of Placing Twenty-five Freshly Hatched Codling Moth Larvae on Each of Three Hundred Ninety-four Apples

Series of apples	Check			Lead arsenate, ½ lb. to 100 gal.						Lead arsenate, 2 lb. to 100 gal.											
				Coarse coverage			Film coverage			Mist coverage			Coarse coverage			Overspray coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	21	0	21	20	0	20	14	2	16	21	1	22	11	2	13	10	8	18	12	1	13
2	18	0	18	20	1	21	11	1	12	22	1	23	7	7	14	11	5	16	10	2	12
3	19	0	19	19	2	21	8	0	8	20	0	20	10	3	13	9	4	13	11	3	14
4	23	0	23	17	3	20	15	2	17	21	0	21	11	3	14			(1)	9	1	10
5	16	0	16	15	2	17	19	3	22	20	3	23	5	4	9	9	4	13	3	8	11
6	16	0	16	12	1	13	12	2	14	20	0	20	7	6	13	7	7	14	9	3	12
7	23	0	23	18	2	20	11	3	14	11	2	13	5	4	9	10	4	14	9	5	14
8	18	0	18	12	2	14	22	0	22	20	0	20	8	5	13	8	4	12	8	4	12
9	24	0	24	16	1	17	12	1	13	18	1	19	16	1	17			(1)	9	2	11
10	19	0	19	15	1	16	17	1	18	21	2	23	12	3	15			(1)	10	2	12
11	21	0	21	14	2	16	16	1	17	18	1	19	12	2	14	11	2	13	11	3	14
12	20	0	20	14	1	15	18	1	19	19	2	21	4	5	9	10	4	14	7	4	11
13	20	0	20	15	4	19	13	1	14	20	2	22	6	2	8	15	1	16	13	4	17
14	19	0	19	10	2	12	11	3	14	15	2	17	3	1	4	11	2	13	10	3	13
15	16	1	17	10	1	11	11	1	12	15	2	17	7	3	10	5	6	11	5	4	9
16	24	0	24	12	5	17	14	2	16	8	7	15	5	2	7	7	3	10	3	3	6
17	16	1	17	16	1	17	15	1	16	15	3	18	6	4	10	8	3	11	8	6	14
18	18	0	18	16	1	17	11	3	14	8	3	11	9	2	11	6	2	8	8	3	11
19	20	0	20	9	2	11	16	1	17	14	1	15	4	1	5	7	1	8	4	2	6
20	24	0	24	8	2	10	12	0	12	16	0	16			(1)	3	1	4	6	3	9
Total	395	2	397	288	36	324	278	29	307	342	33	375	148	60	208	147	61	208	165	66	231
Per cent	79.0	0.4	79.4	57.6	7.2	64.8	55.6	5.8	61.4	68.4	6.6	75.0	31.2	12.6	43.8	34.6	14.4	48.9	33.0	13.2	46.2

Series of apples	Lead arsenate, 4 lb. to 100 gal.											
	Mist coverage			Coarse coverage			Overspray coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	16	4	20	4	12	16	5	5	10	4	8	12
2	15	5	20	6	5	11	8	9	17	4	5	9
3	20	3	23	12	5	17	6	9	15	5	6	11
4	18	2	20	6	6	12	3	2	5	2	4	6
5	14	1	15	11	3	14	8	5	13	3	7	10
6	14	3	17	10	3	13	7	3	10	2	4	6
7	13	3	16	7	2	9	7	4	11	9	4	13
8	11	3	14	7	2	9	8	3	11	6	4	10
9	17	3	20	8	4	12	3	6	9	8	6	14
10	13	3	16	13	2	15	6	3	9	11	2	13
11	15	3	18	8	5	13	5	7	12	5	8	13
12	15	2	17	6	5	11	8	6	14	8	5	13
13	21	0	21	8	6	14	7	4	11	11	2	13
14	16	2	18	5	6	11	7	4	11	6	4	10
15	6	4	10	2	2	4			(1)	6	5	11
16	9	7	16	0	8	8			(1)	5	7	12
17	11	1	12	3	4	7			(1)	5	4	9
18	5	3	8	2	4	6			(1)	3	5	8
19	10	2	12	1	7	8	0	6	6	6	3	9
20	11	2	13	1	5	6	5	3	8	1	2	3
Total	270	56	326	120	96	216	93	79	172	110	95	205
Per cent	54.0	11.2	65.2	24.0	19.2	43.2	23.3	19.8	43.0	22.0	19.0	41.0

Series of apples	Lead arsenate, 8 lb. to 100 gal.											
	Mist coverage			Coarse coverage			Overspray coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	8	9	17	4	6	10	3	14	17	3	9	12
2	22	0	22	6	7	13	1	2	3	3	11	14
3	16	2	18	7	5	12	3	4	7	4	7	11
4	16	3	19	7	3	10	4	5	9	0	7	7
5	10	2	12	6	4	10	10	2	12	5	9	14
6	17	3	20	2	4	6	5	8	13	0	4	4
7	17	2	19	4	2	6	9	4	13	4	5	9
8	12	3	15	3	2	5	4	7	11	4	3	7
9	7	5	12	1	8	9	8	2	10	3	9	12
10	8	4	12	3	6	9	5	5	10	5	5	10
11	15	2	17	2	11	13	4	5	9	3	6	9
12	21	2	23	6	7	13	5	6	11	5	5	10
13	16	2	18	10	6	16	6	5	11	6	5	11
14	13	4	17	7	4	11	2	3	5	2	4	6
15	13	3	16	4	6	10	0	3	3	1	4	5
16	9	3	12	2	7	9	1	4	5	1	8	9
17	6	2	8	0	6	6	2	6	8	1	6	7
18	7	6	13	3	9	12	3	2	5	0	3	3
19	7	2	9	1	4	5	2	3	5	1	1	2
20	9	2	11	0	2	2	1	3	4	0	0	0
Total	249	61	310	78	109	187	78	93	171	51	111	162
Per cent	49.8	12.2	62.0	15.6	21.8	37.4	15.6	18.6	34.2	10.2	22.2	32.4

Series of apples	Lead arsenate, 16 lb. to 100 gal.								
	Mist coverage			Coarse coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1		(2)		3	5	8	1	3	4
2				4	5	9	0	3	3
3				5	7	12	0	6	6
4				4	6	10	1	4	5
5				4	5	9	0	5	5
6				2	5	7	0	4	4
7				4	11	15	1	4	5
8				3	3	6	1	6	7
9				1	9	10	0	7	7
10				3	3	6	3	5	8
11	14	4	18	3	5	8			(1)
12	14	5	19	1	5	6			(1)
13	13	1	14	4	5	9			(1)
14	11	2	13	3	5	8			(1)
15	2	6	8	1	4	5	1	3	4
16	6	4	10	0	3	3	0	4	4
17	7	6	13	0	4	4	1	1	2
18	2	6	8	2	2	4	0	4	4
19	4	5	9	0	1	1	0	3	3
20	0	2	2	0	2	2	0	1	1
Total	73	41	114	47	95	142	9	63	72
Per cent	29.2	16.4	45.6	9.4	19.0	28.4	2.3	15.8	18.0

(1) Tests omitted or data lost by accident.

(2) Tests one to ten intentionally omitted.

TABLE 2

RESULTS OF PLACING TWENTY-FIVE FRESHLY HATCHED CODLING MOTH LARVAE EACH ON APPLES HANGING NATURALLY ON TREES

Series of apples	Lead arsenate, 2 lb. to 100 gal.								
	Mist coverage			Coarse coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	18	2	20	8	3	11	6	4	10
2	12	0	12	6	4	10	7	2	9
3	17	0	17	11	3	14	8	4	12
4	....	....	(1)	5	1	6	10	2	12
Total	47	2	49	30	11	41	31	12	43
Per cent	62.7	1.7	66.7	30.0	11.0	41.0	31.0	12.0	43.0

Series of apples	Lead arsenate, 4 lb. to 100 gal.						Check		
	Coarse coverage			Film coverage			Unsprayed		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	4	6	10	4	6	10	22	0	22
2	3	2	5	7	2	9	18	0	18
3	4	3	7	4	6	10	16	0	16
4	....	....	(1)	....	....	(1)	20	0	20
Total	11	11	22	15	14	29	76	0	76
Per cent	14.7	14.7	29.3	20.0	18.7	38.7	76.0	0.0	76.0

(1) Tests omitted because of accidents or insufficient larvae.

The following comparison of the results of the laboratory and the orchard tests indicates that the spray may be slightly more effective under orchard conditions, although the differences shown easily fall within the range of experimental error.

TABLE 3

A COMPARISON OF THE PERCENTAGES OF LARVAE CAUSING INJURY IN LABORATORY AND ORCHARD TESTS

	Laboratory tests			Orchard tests		
	Entrances, per cent	Stings, per cent	Total injury, per cent	Entrances, per cent	Stings, per cents	Total injury, per cent
Lead arsenate, 2 lb. to 100 gal.:						
Mist coverage	68.4	6.6	75.0	62.7	1.7	66.7
Coarse coverage	31.2	12.6	43.8	30.0	11.0	41.0
Film coverage	33.0	13.2	46.2	31.0	12.0	43.0
Lead arsenate, 4 lb. to 100 gal.:						
Mist coverage	54.0	11.2	65.2	....	....	....
Coarse coverage	24.0	19.2	43.2	14.7	14.7	29.3
Film coverage	22.0	19.0	41.0	20.0	18.7	38.7

Variation in Number of Injuries per Apple

Examination of table 1 brings out the fact that there was a wide variation in the results of the tests. The number of entrances among the unsprayed apples varied from sixteen to twenty-four, while with some of the spray combinations the number ranged from eight to twenty-four among apples having the same treatment. It is believed that an important cause for this variation was that too many apples were run at a time. The twenty-two apples of a series required five hundred fifty larvae. Sometimes the larvae hatched rapidly and they could not be properly transferred, while at other times an insufficient number were available to finish a series and it was necessary to complete the transfer on the following day. The range in number of injuries per apple was much less in other studies in which fewer apples were used in a series. Other causes for variations have been mentioned under the topic, Methods and Technique.

Results of Special Interest

Four facts that are quite contrary to what might have been expected are shown in tables 1 and 2. First, the lead arsenate was comparatively ineffective in protecting the apples. The general belief has been that apples so thoroughly sprayed would be only slightly injured if at all, whereas, with the standard concentration of lead arsenate at two pounds to one hundred gallons over thirty per cent of the larvae entered unharmed and over forty per cent either entered or made stings. Second, the mist coverage was very much less effective than the coverages of large spots, whereas, there has been a widely accepted opinion among spray authorities that in orchard spraying the mist coverage is the most effective. Third, the film coverage gave scarcely any better protection, except with the higher concentrations, than the spotted coverages, whereas, it might have been expected on theoretical grounds that the film coverage would give much greater protection. Fourth, increasing the concentration of the spray resulted in decidedly decreasing the percentage of larvae that succeeded in effecting entrances, whereas, it has been generally believed in orchard spraying that very little if anything is gained by using lead arsenate in greater proportion than two pounds to one hundred gallons of water.

Protectiveness of Different Coverages

A summary of the laboratory tests with spray concentrations of two, four and eight pounds of lead arsenate to one hundred gallons of water, gives the following percentages of injury:

	Entrances, per cent	Stings, per cent	Total injury, per cent
Mist coverage	57.4	10.0	67.4
Coarse coverage	23.4	18.0	41.4
Overspray coverage	24.0	17.6	41.6
Film coverage	21.7	18.1	39.8

This is shown graphically in figure 5.

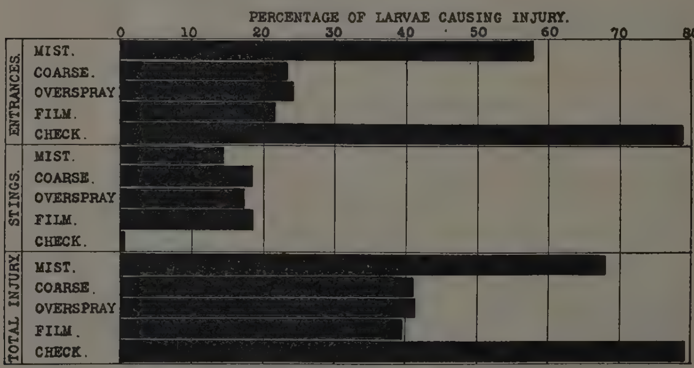

Fig. 5. Graphs based on the data of table 1, indicating the protectiveness of different spray coverages.*

The protectiveness of different coverages is shown in detail in table 4 and by the curves in figure 10. It will be noted that the coarse, overspray and film coverages were about equal in protectiveness up to the four-pound concentration. Above this concentration the film coverage gave greater protection. In all instances the mist coverage gave the poorest protection.

* The graphs represent the average percentage of larvae causing injury to apples sprayed with concentrations of two, four and eight pounds to one hundred gallons. These were the only concentrations in which tests were made with all four types of coverages. The mist and overspray coverages were omitted in the one-half-pound concentration and the overspray coverage omitted in the sixteen-pound concentration.

TABLE 4

SUMMARY OF THE DATA INCLUDED IN TABLE 1

Coverage and concentration	Entrances, per cent	Stings, per cent	Total injury, per cent
Lead arsenate, ½ lb. to 100 gal.:			
Coarse coverage	57.6	7.2	64.8
Film coverage	55.6	5.8	61.4
Lead arsenate, 2 lb. to 100 gal.:			
Mist coverage	68.4	6.6	75.0
Coarse coverage	31.2	12.6	43.8
Overspray coverage	34.6	14.4	48.9
Film coverage	33.0	13.2	46.2
Lead arsenate, 4 lb. to 100 gal.:			
Mist coverage	54.0	11.2	65.2
Coarse coverage	24.0	19.2	43.2
Overspray coverage	23.3	19.8	43.0
Film coverage	22.0	19.0	41.0
Lead arsenate, 8 lb. to 100 gal.:			
Mist coverage	49.8	12.2	62.0
Coarse coverage	15.6	21.8	37.4
Overspray coverage	15.6	18.6	34.2
Film coverage	10.2	22.2	32.4
Lead arsenate, 16 lb. to 100 gal.:			
Mist coverage	29.2	16.4	45.6
Coarse coverage	9.4	19.0	28.4
Film coverage	2.3	15.8	18.0
Check, unsprayed	79.0	.4	79.4

In the course of the experiments special attention was given to the behavior of the larvae, with a view to finding explanations for the results obtained.

Factors relating to the protectiveness of the mist coverage.—It has long been recognized that some larvae succeed in effecting entrances into sprayed apples by burrowing through the areas between deposits of lead arsenate. Presumably, the larger the deposits, the larger the unprotected areas between deposits and the more room for larvae to enter unharmed by the poison. Owing to this conception the idea has become widely accepted among authorities on spraying that, to be most effective, spray should be applied in such a manner as to cover the apples of a tree with fine particles of mist. The assumption apparently has been that the resultant small deposits of poison would be so close together that there would not be room for larvae to enter between them; that is, the mist coverage on apples has been regarded as practically tantamount to having them covered by an unbroken film. As shown by these studies, this assumption is seriously in error. When

the deposits of lead arsenate were from one-half millimeter to two millimeters in diameter, the latter representing an area about the size of the head of an ordinary pin, there was ample space for larvae to enter between the deposits. This is well illustrated by the photographs in figure 6. The photograph on the left shows an apple natural size, having a fairly typical mist coverage of lead arsenate. A freshly hatched codling moth larva was placed on the apple and observed until it started to burrow through the skin. A common pin was then inserted in the side of the apple close to the larva. The microphotograph was then taken. The head of the pin measured slightly less than two millimeters in diameter.

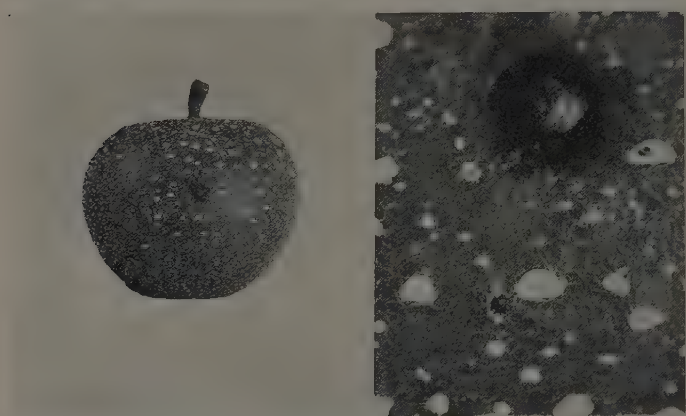

Fig. 6. Left: an apple having a mist coverage of lead arsenate, with a pin inserted in the side. Right: microphotograph of the same apple, showing a freshly hatched codling moth larva in the act of burrowing into the apple.

Writers on codling moth control, wishing to emphasize the necessity of having apples thoroughly covered with spray, have sometimes stated that the larva makes a hole about the size of a pin head on entering the apple. The head of an ordinary pin, however, is more than twenty-five times the area of the entrance hole of a newly hatched larva. The question may be raised whether the larva does not enlarge the hole after entering the apple. Such behavior was not observed in any of these studies, neither were evidences of it found in examining apples in the orchard.

Where the deposits of lead arsenate were very minute, the larvae appeared to burrow through them or to dig them away without being affected by the poison. This was especially the case with the lower concentrations of spray.

Another reason for the lower protectiveness of the mist coverage appeared to be that the small deposits were so nearly even with the surface of the apple that they did not stimulate the thigmotactic proclivities of the larvae, as did the large deposits of the coarse and overspray coverages.

Factors relating to the protectiveness of the coarse coverage.—The largest deposits of the coarse coverage were approximately eight millimeters in diameter. Notwithstanding the numerous large interspaces which

Fig. 7. An overspray coverage of lead arsenate in concentration of two pounds to one hundred gallons of water. The arrow points to an entrance made through the upper part of a deposit.

appeared to be relatively unprotected, less than one-half as many larvae entered the apples with coarse coverage as entered those with the mist coverage. There seemed to be four reasons why the coarse coverage gave so much better protection than theoretically might have been expected. First, the larvae exhibited a tendency to rest upon and examine the deposits of lead arsenate and it seemed probable that some larvae became poisoned incidentally in doing this. Second, the relatively thick edges of the large deposits stimulated the thigmotactic reactions of the larvae, which resulted in many of them attempting to dig through the edges and thus becoming poisoned. Third, although

there appeared to be relatively large unprotected areas between the larger deposits, close examination revealed many small deposits, resembling those of a mist coverage, on these areas. The small deposits were doubtless of some influence in preventing entrances. Fourth, it seemed evident that the apples with the coarse coverage had more surface actually covered with poison than the apples with the mist coverage.

In case of the coarse coverage of one-half pound to one hundred gallons, many entrances were made directly through deposits of poison.

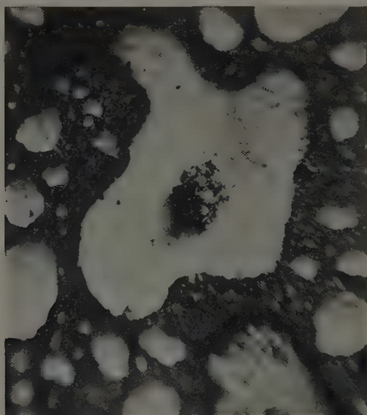

Fig. 8. Microphotograph showing where a larva had burrowed through a heavy deposit of lead arsenate.

With the concentration of two pounds to one hundred gallons, entrances were sometimes made through the thin upper parts of the large deposits. An example of this is shown in figure 7.

Two or three instances were observed where larvae had burrowed directly through heavy deposits of lead arsenate. An example of this is shown in the microphotograph in figure 8. The fresh castings which were being thrown out when the photograph was taken was evidence that the larva was alive. After taking the picture the burrow was opened. The larva had made a typical excavation under the skin. It appeared to be unaffected by the poison but no special observations were made to determine this point with certainty. The probable explanation of such occurrences is discussed near the close of this paper.

Factors relating to the protectiveness of the overspray coverage.—The distribution of the lead arsenate in case of the overspray coverage was much more irregular than that of the coarse coverage. Wherever a

large drop of spray ran down just before spraying was stopped, the path of the drop presented a relatively large area which, on casual observation, appeared to bear very little poison. It should be mentioned that special care was taken not to cause any drop to run down after spraying was completed. In general, the oversprayed apples appeared to be less effectively covered than those of the coarse coverage yet the protectiveness of the two coverages was about the same. This fact seemed to be due in part, at least, to three factors: first, it was noticed that some deposits of the overspray coverage were larger and thicker than any of the coarse coverage; second, as soon as a drop ran down other drops immediately began forming in its path; third, it is possible that a thin film of poison may have adhered to the apple skin as the drops ran down.

TABLE 5

RESULTS OF TESTS WITH APPLES OVERSPRAYED, AND WITH APPLES HEAVILY OVERSPRAYED AND THEN LIGHTLY SHAKEN

Series of apples	Lead arsenate, 2 lb. to 100 gal.							
	Typical overspray coverage				Apples heavily oversprayed and lightly shaken			
	Entrances	Stings	Total	mmg. As_2O_3 per sq. cm.	Entrances	Stings	Total	mmg. As_2O_3 per sq. cm.
1	6	4	10		11	3	14	
2	7	7	14		14	3	17	
3	6	4	10		8	5	13	
4	8	4	12		10	6	16	
Total number	27	19	46		43	17	60	
Per cent	27.0	19.0	46.0		43.0	17.0	60.0	
Average				8.63				4.20

The third factor has been a matter of considerable speculation. Some persons have believed that an oversprayed apple is covered by a very thin film as a result of numerous drops running down and it has been supposed that such a film would be effective in preventing injury by codling moth larvae. In order to secure information on this, four apples were heavily oversprayed by applying twenty cubic centimeters of spray to each. Immediately after spraying, the apples were lightly shaken in order to cause the larger drops to run off. Another four apples having a typical overspray coverage were used as checks. Twenty-five freshly hatched larvae were then placed on each of the apples. Finally, determinations were made of the arsenic and computations made of the average number of micromilligrams of arsenious oxide per square centimeter of surface for each group of apples. The results of the test are shown in table 5. The data indicate that if a

film of lead arsenate formed on the paths of the drops which ran off, it was of slight effect in protecting the apples. About one-half as much arsenic occurred on the apples heavily sprayed and shaken as on those typically oversprayed.

The coverage resulting from overspraying and shaking probably approximates that resulting from overspraying apple trees in the orchard when wind is blowing. The experiment indicates that almost half the value of the spray may be lost under such a condition.

Factors relating to the protectiveness of the film coverage.—So much emphasis has been placed upon "lack of thoroughness" in applying spray as a leading cause for failure to control the codling moth that a great many persons have come to believe that complete coverage would result in complete protection. When no other explanation for a "wormy" crop of apples has seemed plausible, the sprays being properly timed and the applications being made with exceptional thoroughness, it has been supposed that the poor control was due to the larvae entering between deposits of poison. Spreaders and the film type of coverage were brought into prominence on the theory that if the deposits of lead arsenate could be eliminated and the apples covered with a complete film, much better protection would result.

Examination of tables 1 and 2 show clearly that other factors than completeness of coverage are involved. With the concentrations of one-half, two and four pounds to one hundred gallons, about as many larvae caused injury through the film coverage as through the coarse and overspray coverages. The film coverage of eight and sixteen pounds to one hundred gallons, however, resulted in fewer entrances than the spotted coverages of the same concentrations.

The most important factor in the protectiveness of the film coverage is the thickness of the film. The newly hatched larva digs or burrows through the apple skin; it does not literally eat through. Bits of skin are cut off with the mandibles and cast aside. Very little, and sometimes none at all, is swallowed (see page 446). If the film of lead arsenate is thin, as was the case with the lower concentrations, many larvae will not swallow any poison or not enough to kill them. The thicker the coating of poison, the greater the probability of the larvae obtaining lethal doses of arsenic in digging through the skin. Further evidence on this matter is given in table 8 and figures 12, 13 and 18, and the discussion relating to these.

Two other reasons may be mentioned why the film coverage did not give materially better protection than the spotted coverages: first, the lead arsenate of the film adhered firmly to the surfaces of the apples and this minimized the possibility of the larvae gathering up particles

of poison while crawling over the apples; second, the film coverage presented no irregularities which would tend to stimulate the larvae to bite against the poison as apparently occurred in case of the spotted coverages.

Apples with Two Applications of Spray

As a possible explanation of the relative ineffectiveness of the lead arsenate in protecting the apples in the foregoing tests, the suggestion was made that perhaps the spotted coverages would have given better results if two applications of spray had been applied. It was thought that the drops of the second application might form on the uncovered

TABLE 6

Results of Placing Twenty-five Larvae Each on Apples Receiving Two Applications of Spray. (For the purpose of comparison, results of single spray applications, taken from table 1, are also included.)

Series of apples	Lead arsenate, 2 lb. to 100 gal.											
	Mist coverage			Coarse coverage			Overspray coverage			Film coverage		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	16	2	18	4	7	11	2	6	8	4	6	10
2	12	3	15	4	6	10	4	5	9	5	6	11
3	14	1	15	8	2	10	3	5	8	5	4	9
4	10	3	13	6	2	8	8	2	10	5	5	10
Total number	52	9	61	22	17	39	17	18	35	19	21	40
Per cent	52.0	9.0	61.0	22.0	17.0	39.0	17.0	18.0	35.0	19.0	21.0	40.0
Percentage of larvae causing injury in tests of one application. (Table 1.) Lead arsenate:												
2 lb. to 100 gal.	68.4	6.6	75.0	31.2	12.6	43.8	34.4	13.8	46.2	33.0	13.2	46.2
4 lb. to 100 gal.	54.0	11.2	65.2	24.0	19.2	43.2	23.3	19.8	43.0	22.0	19.0	41.0

spaces left by the first application. In order to secure information on this point, several tests were made in which apples were sprayed twice, the second application being applied after the first had dried. The calyx cavities were filled with shellac and the apples suspended as in previous tests. Larvae were then place on the apples. The results of these tests are given in table 6. The two applications of spray at two pounds to one hundred gallons gave about the same protection as the one application of spray at four pounds to one hundred gallons shown

in table 1. While applying the spray it was noticed that the drops of the second application invariably formed on the deposits of the first application. Consequently, the interspaces resulting from the two applications were about as large as those of the single application

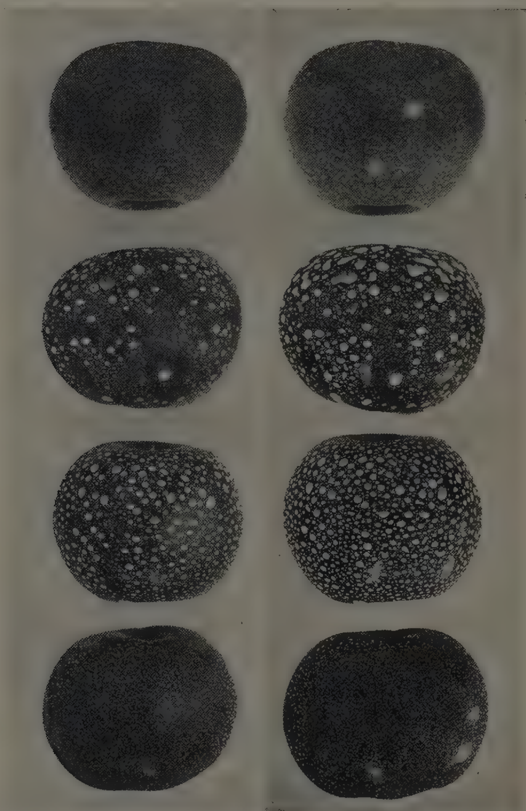

Fig. 9. Left: apples with one application of spray. Right: the same apples after a second application of spray had been applied.

(fig. 9). It appeared that the principal effect of the second spray was that of doubling the thickness of the deposits of the first. Observations in orchard spraying revealed the same tendency of the drops of the second and third applications to collect on the deposits of the first.

Ratio of Entrances to Stings

It will be observed in all the tests that the percentage of entrances varied inversely with the percentage of stings, except in the concentration of sixteen pounds to one hundred gallons in which there occurred a reduction in both entrances and stings. This tends to confirm the belief advanced by Melander[53] that the ratio of entrances to stings affords the best basis for judging the efficiency of orchard spraying. A high proportion of stings in relation to entrances indicates a high percentage of larvae killed.

Quantity of Lead Arsenate in Relation to Protection

Concentration of spray in relation to protection.—As previously mentioned there has been a decided disposition on the part of spray authorities to regard the amount of poison on the apple as a matter of relatively minor importance in codling moth control. Analyses that have been reported have suggested that scarcely more than a trace of lead arsenate over the surface is sufficient to prevent entrances. The conception apparently has been that if one apple was sprayed all over with a concentration of two pounds to one hundred gallons and another sprayed in the same manner with a concentration of four pounds to one hundred gallons, the uncovered interspaces on the one would be just as large and as numerous as on the other. No larva, presumably, would be able to go through a deposit of the lower concentration and, therefore, nothing could be gained by using a higher concentration.

In these studies it was found that increasing the concentration of lead arsenate resulted in all cases in decreasing the percentage of entrances and, to a less extent, in reducing the percentage of total injury. This is graphically illustrated in figure 10. It will be observed that the curve representing the entrances made through the film coverage is nearly a straight line, indicating a fairly constant ratio between concentrations and entrances. The curves of the mist, coarse and overspray coverages are less regular than the curve of the film coverage. It appeared that doubling the concentration in case of the film coverage resulted in uniformly doubling the thickness of the film, thereby uniformly decreasing the percentage of larvae that succeeded in digging through; while doubling the concentration of the spotted coverages resulted in doubling the thickness of the deposits without very materially decreasing the size of the interspaces (fig. 12).

In table 7 is given a summary of the data of table 1, including the average percentage of injury for the four types of spray coverages. The average percentage of injury in relation to concentration is shown

TABLE 7

Summary of Data from Table 1, Showing the Relation of Lead Arsenate Concentration to Percentage of Larvae Causing Injury

Type of coverage	Lead arsenate, 2 lb. to 100 gal.			Lead arsenate, 4 lb. to 100 gal.			Lead arsenate, 8 lb. to 100 gal.			Lead arsenate, 16 lb. to 100 gal.		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
Mist	68.4	6.6	75.0	54.0	11.2	65.2	49.8	12.2	62.0	29.2	16.4	45.6
Coarse	31.2	12.6	43.8	24.0	19.2	43.2	15.6	21.8	37.4	9.4	19.0	28.4
Overspray	34.4	13.8	48.9	23.3	19.8	43.0	15.6	18.6	34.2	......	......	......
Film	33.0	13.2	46.2	22.0	19.0	41.0	10.2	22.2	32.4	2.3	15.8	18.0
Average	42.2	11.6	53.8	31.2	17.2	48.4	22.8	18.7	41.5	11.2	17.3	28.5

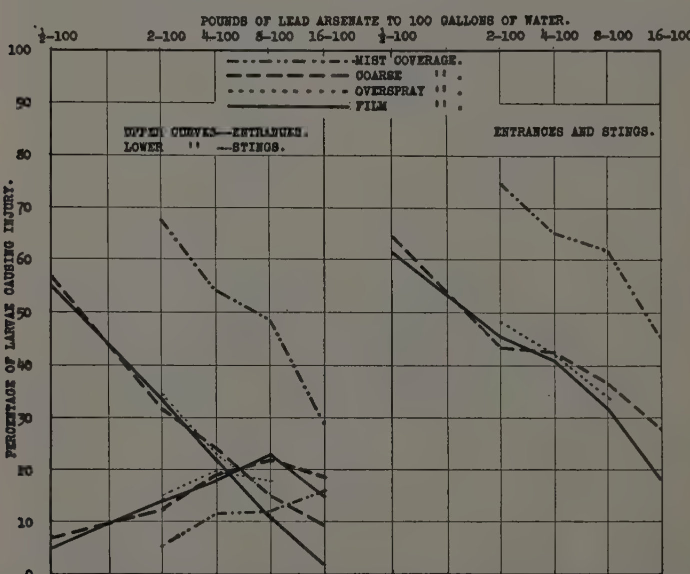

Fig. 10. Curves based on data of table 1, showing relation of lead arsenate concentration to the percentage of larvae causing injury.

by the curves in figure 11. It will be noted by the averages that doubling the amount of lead arsenate resulted in each case in reducing the number of entrances by approximately eleven per cent. Increasing from two pounds to four pounds reduced the total injury 5.4 per cent; increasing from four to eight pounds reduced the total injury 6.9 per cent; increasing from eight to sixteen pounds reduced the total injury 13.0 per cent.

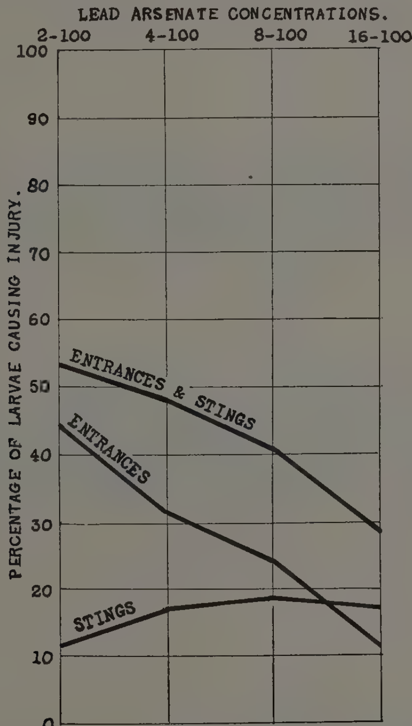

Fig. 11. Curves based on data of table 1, showing average percentage of larvae causing injury through mist, coarse, overspray and film coverages in relation to lead arsenate concentration.

Thickness of lead arsenate deposit in relation to protection.—Determinations were made of the arsenic in all the tests recorded in table 1, and from this was computed the average amount of arsenic per square centimeter of apple surface. The data, together with percentages of injury, are given in condensed form in table 8. In all instances the percentage of entrances varied inversely with the amount of arsenic

per square centimeter, while up to the point corresponding to the eight-pound concentration, the percentage of stings varied directly with the amount of arsenic per square centimeter.

Although the film coverage gave slightly better protection than the coarse coverage, the amount of arsenic per square centimeter was about one-third that of the coarse coverage. This indicates that the film coverage is three times as efficient as the coarse coverage. The relative efficiencies of the different coverages are shown by the curves in figure 13. It will be noted that twenty-five micromilligrams of arsenic (As_2O_3) per square centimeter resulted in 2.3 per cent of entrances with

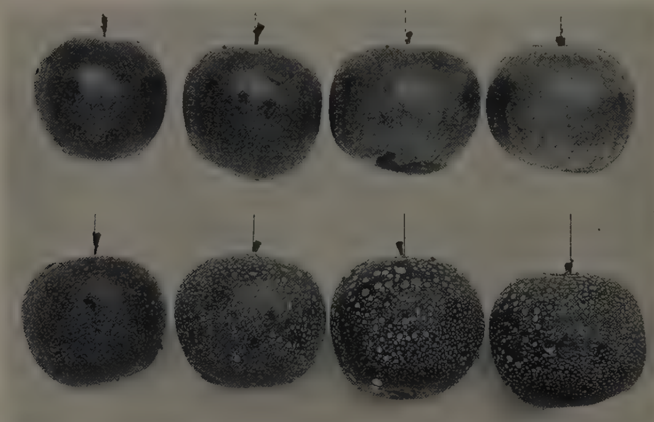

Fig. 12. Apples sprayed with lead arsenate in concentrations of (left to right) one-half, two, four and eight pounds to one hundred gallons. Upper, film coverage; lower, coarse coverage.

the film coverage while seventy-seven and one-half micromilligrams in case of the coarse coverage resulted in 9.4 per cent of entrances. By extending the curves in the first graph, it appears that complete protection against entrances would be secured at about thirty micromilligrams per square centimeter with the film coverage and at about one hundred and fifty micromilligrams with the coarse coverage. Similarly, extending the curves in the second graph, indicates that complete freedom from injury would result at about forty micromilligrams in case of the film coverage and at over two hundred micromilligrams with the coarse coverage. Still further evidence of the greater efficiency of the film coverage is that the percentage of stings began to decrease at approximately fourteen micromilligrams, whereas, decrease in stings in case of the coarse coverage began at approximately thirty-five micromilligrams.

TABLE 8

Average Amount of Arsenious Oxide per Square Centimeter of Apple Surface and Percentages of Injury for the Tests Shown in Table 1

Lead arsenate concentration	Mist coverage				Coarse coverage			
	mmg. As_2O_3 per sq. cm.	Per cent of injury			mmg. As_2O_3 per sq. cm.	Per cent of injury		
		Entrances	Stings	Total		Entrances	Stings	Total
2 lb. to 100 gal.	2.10	68.4	6.6	75.0	9.78	31.2	12.6	43.8
4 lb. to 100 gal.	3.04	54.0	11.2	65.2	17.45	24.0	19.2	43.2
8 lb. to 100 gal.	4.92	49.8	12.2	62.0	34.70	15.6	21.8	37.4
16 lb. to 100 gal.	13.74	29.2	16.4	45.6	77.51	9.4	19.0	28.4
Average	5.01	53.4	10.9	64.3	34.86	19.9	18.2	38.2

Lead arsenate concentration	Overspray coverage				Film coverage			
	mmg. As_2O_3 per sq. cm.	Per cent of injury			mmg. As_2O_3 per sq. cm.	Per cent of injury		
		Entrances	Stings	Total		Entrances	Stings	Total
2 lb. to 100 gal.	8.20	34.6	14.4	48.9	3.83	33.0	13.2	46.2
4 lb. to 100 gal.	17.17	23.3	19.8	43.0	6.86	22.0	19.0	41.0
8 lb. to 100 gal.	32.83	15.6	18.6	34.2	13.87	10.2	22.2	32.4
16 lb. to 100 gal.	......	......	......	......	24.99	2.3	15.8	18.0
Average	20.65	24.0	17.6	41.6	11.43	17.6	17.6	35.2

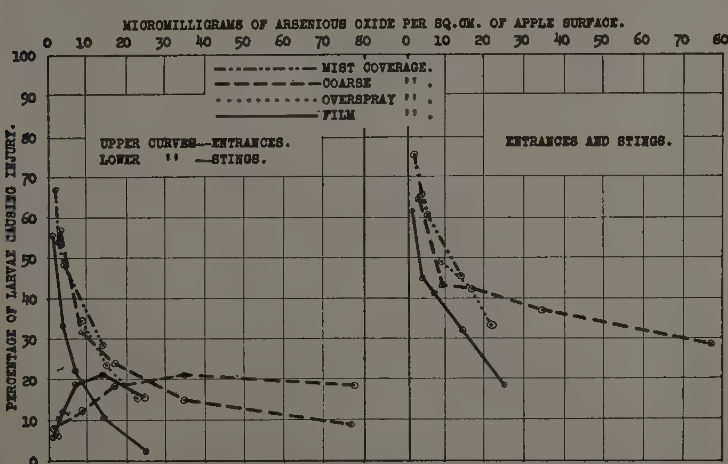

Fig. 13. Curves based on the data of table 8, showing relation of quantity of arsenious oxide per square centimeter of apple surface to percentage of larvae causing injury.

LARVAE ON APPLES DUSTED WITH LEAD ARSENATE

Scores of orchard experiments have been made in various parts of the country to determine the relative merits of applying lead arsenate as a dust and as a spray. The experimental data accumulated have been so erratic that the question of spraying versus dusting is about as unsettled now as it was ten or twenty years ago. The removal of the dust by rain and wind is doubtless an important factor in the efficacy of the dust treatment. It seems almost incredible that in a great many reports of orchard dusting experiments no mention whatsoever has been made of the possible influence wind and rainfall may have had on the results.

Studies Made in the Laboratory

In order to obtain more information on the efficacy of the dusting method of codling moth control, seven series of apples were dusted uniformly with a dry mixture consisting of ninety per cent flowers of sulfur, approximately two-hundred mesh in fineness, and ten per cent lead arsenate. The material was applied with a small hand duster. The calyx cavities of the apples were filled with shellac and the apples suspended as in previous tests. The covering of dust was such as to be decidedly visible to the unaided eye. Certain of the apples were blown against strongly with the breath; others were lightly sprayed with distilled water until drops ran down over the whole surface of each apple; and on others the dust covering was left undisturbed. Twenty-five freshly hatched codling moth larvae were then transferred to each apple. The results of the tests are given in table 9. Blowing against the apples and spraying them greatly reduced the protectiveness of the dust covering. It should be mentioned that the dust was not applied to the apples with force. It was found later that when dust strikes the apple with considerable force, it adheres more firmly than when it falls lightly upon the surface.

Studies Made in the Orchard

Tests on the efficacy of the dust treatment were also made with apples in their natural positions on the trees, similar to the orchard spray tests reported in table 2. The results of these tests, as shown in table 10, agree closely with those made in the laboratory.

The dust coverage when undisturbed was much more effective in comparison with the spray than was expected. Less than one-half as

TABLE 9

RESULTS OF PLACING TWENTY-FIVE LARVAE EACH ONTO APPLES DUSTED WITH LEAD ARSENATE

Series of apples	Dust undisturbed			Apples blown against			Apples lightly sprayed			Check		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	2	7	9	7	6	13	11	2	13	18	1	19
2	4	6	10	5	3	8	12	0	12	18	2	20
3	4	3	7	11	1	12	16	0	16	16	0	16
4	2	2	4	13	0	13	15	2	17	21	0	21
5	5	1	6	14	0	14	16	0	16	17	0	17
6	1	3	4	1	5	6	10	3	13	17	1	18
7	5	3	8	2	2	4	12	2	14	17	0	17
Total number	23	25	48	53	17	70	92	9	101	127	4	131
Per cent	13.1	14.3	27.5	30.3	9.7	40.0	52.6	5.2	57.7	72.6	2.3	74.9

many entrances were made through the dust coverage as through the coverage of spray in concentration of two pounds of lead arsenate to one hundred gallons of water. Observations on the behavior of the larvae indicate that the reasons for the greater protectiveness of the dust are: first, the larva is more likely to gather up and swallow particles of poison on the dusted apple than on the sprayed; second, the dust accumulates on the spinneret and on other parts of the head and body, which greatly impedes the activity of the larva. Preparatory to digging into the apple, the larva spins a more or less distinct mat of fibers with which to hold fast while cutting away the skin. The dust

TABLE 10

RESULTS OF PLACING TWENTY-FIVE LARVAE EACH ONTO DUSTED APPLES HANGING NATURALLY ON TREES

Series of apples	Dust undisturbed			Apples blown against			Apples lightly sprayed			Check		
	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total	Entrances	Stings	Total
1	3	6	9	9	4	13	12	3	15	22	0	22
2	3	4	7	11	2	13	14	0	14	18	0	18
3	5	4	9	5	6	11	9	3	12	16	0	16
4	2	2	4	6	4	10	12	2	14	20	0	20
Total number	13	16	29	31	16	47	47	8	55	76	0	76
Per cent	13	16	29	31	16	47	47	8	55	76	0	76

seems especially to frustrate the larva in this operation. If the dust coating adheres firmly to the surface of the apple, however, the larva is not appreciably inconvenienced. Apples which had a heavy firm covering of road dust were entered by larvae just as readily as apples having no dust covering.

LARVAE ON APPLE LEAVES SPRAYED WITH LEAD ARSENATE

During the months of May and June when the apples are small a high percentage of codling moth eggs are laid on the leaves of apple trees. It has been supposed that many larvae become poisoned by feeding on sprayed leaves before finding apples. The following laboratory studies were made to obtain further information on this subject.

Fig. 14. Cuttings of apple branches ready for tests.

Early in June growing ends of apple branches were cut off and placed in vessels of water, as shown in figure 14. Twenty-five cuttings, eighteen inches long, were used. Care was taken to select cuttings with the same number of leaves and in other respects alike. The upper and under surfaces of the leaves and the bark of certain of the cuttings were sprayed with lead arsenate. An unsprayed apple was fastened to each cutting by diagonally clipping off the apple stem, covering it with glue and then firmly fixing the cut end to the bark with a small insect pin. In other tests the leaves were left unsprayed and sprayed apples were fastened to the bark. The calyx cavities of the apples were filled with shellac. The coarse coverage of lead arsenate spray was used on both leaves and apples. After the spray had dried,

twenty-five freshly hatched larvae were placed on the fourth leaf above the apple on each cutting. The larvae had to crawl approximately the same distance on each cutting in order to reach the apples. Three days after transferring the larvae, careful examinations were made of the apples, leaves and stems, and records made of the number of live larvae and of various injuries. The results of the tests are given in table 11.

TABLE 11

SHOWING THE RESULTS OF TRANSFERRING TWENTY-FIVE LARVAE EACH TO CUTTINGS FROM THE GROWING ENDS OF APPLE BRANCHES TO WHICH APPLES WERE ARTIFICIALLY ATTACHED

Treatment	Cutting	Live larvae in apples	Live larvae in stems	Live larvae in leaves	Total live larvae	Stings on apples	Feeding places on stems	Feeding places on leaves	Total feeding places on leaves and stems
	1	15	5	1	21	0	0	1	1
	2	11	3	2	16	0	2	5	7
	3	12	3	5	20	0	2	2	4
Check—unsprayed.	4	9	3	4	16	0	1	3	4
	5	7	2	4	13	0	2	4	6
Total number		54	16	16	86	0	7	15	22
Per cent		43.2	12.8	12.8	68.8	0.0	5.6	12.0	16.0
	1	10	2	0	12	0	0	3	3
Leaves sprayed with lead	2	6	2	2	10	0	3	1	4
arsenate, 2 lb. to 100 gal.	3	6	0	2	8	0	1	3	4
	4	3	2	2	7	0	1	3	4
	5	3	0	0	3	0	1	1	2
Total number		28	6	6	40	0	6	11	17
Per cent		22.4	4.8	4.8	32.0	0.0	4.8	8.0	13.6
	1	6	1	1	8	2	2	5	7
	2	6	1	2	9	1	2	1	3
Apples sprayed with lead	3	5	4	1	10	0	1	3	4
arsenate, 2 lb. to 100 gal.	4	10	3	0	13	1	2	1	3
	5	3	1	4	8	0	2	2	4
Total number		30	10	8	48	4	9	12	21
Per cent		24.0	8.0	6.4	38.4	3.2	7.2	9.6	16 8
	1	12	2	2	16	0	0	0	0
	2	7	1	3	11	0	1	3	4
Leaves sprayed with lead	3	11	1	2	14	0	2	4	6
arsenate, ½ lb. to 100 gal.	4	9	1	0	10	0	1	4	5
	5	6	1	4	11	0	2	1	3
Total number		45	6	11	62	0	6	12	18
Per cent		36.0	4.8	8.8	49.6	0.0	4.8	9.6	14.4
	1	7	0	0	7	1	1	2	3
	2	5	0	0	5	0	0	3	3
Leaves sprayed with lead	3	3	1	0	4	0	0	6	6
arsenate, 4 lb. to 100 gal.	4	2	0	1	3	0	1	1	2
	5	0	0	1	1	0	2	2	4
Total number		17	1	2	20	1	4	14	18
Per cent		13.6	0.8	1.6	16.0	0.8	3.2	11.2	14.4

Relative Value of Spray on Leaves and on Apples

The relative value of spray on the leaves and bark, and on the apples is best indicated by the number of live larvae found at the end of the third day after transferring. These data are summarized in table 12. A comparison of the concentrations of two pounds to one hundred gallons, shown in columns three and five, indicates that more larvae were killed by the spray on the leaves and bark than by the spray on the apples. The extensiveness of injury to the leaves and stems, however, was very much greater than that which occurs under orchard conditions. Examination, for example, of eight branches on which were 4744 leaves and sixteen apples, on a tree so badly infested with codling moth that there was an average of twelve injuries per apple, revealed only three feeding burrows in leaves and stems. This examination was made on August 22. It is believed, therefore, that only limited importance may be attached to the laboratory tests as regards the relative value of spray on leaves and on fruit.

TABLE 12

Summary of Data on Tests with Cuttings from Growing Ends of Apple Branches

	Check unsprayed	Leaves and bark sprayed with lead arsenate			Apples sprayed lead arsenate
		½ lb. to 100 gal.	2 lb. to 100 gal.	4 lb. to 100 gal.	2 lb. to 100 gal.
Live larvae in apples	43.2	36.0	22.4	13.6	24.0
Live larvae in stems	12.8	4.8	4.8	0.8	8.0
Live larvae in leaves	12.8	8.8	4.8	1.6	6.4
Total	68.8	49.6	32.0	16.0	38.4

It is especially important to note that increasing the concentration of the lead arsenate in spraying the cuttings resulted in decidedly increasing the percentage of larvae killed. Two pounds to one hundred gallons resulted in thirty-two per cent live larvae and four pounds to one hundred gallons resulted in sixteen per cent live larvae.

LARVAE ON SECTIONS OF GLASS SPRAYED AND DUSTED WITH LEAD ARSENATE

In order to obtain further data on the relative protectiveness of different types of spray coverages and different lead arsenate concentrations, and also to secure further information on the manner in which codling moth larvae become poisoned, a number of studies were made in which freshly hatched larvae were placed on sections of glass treated

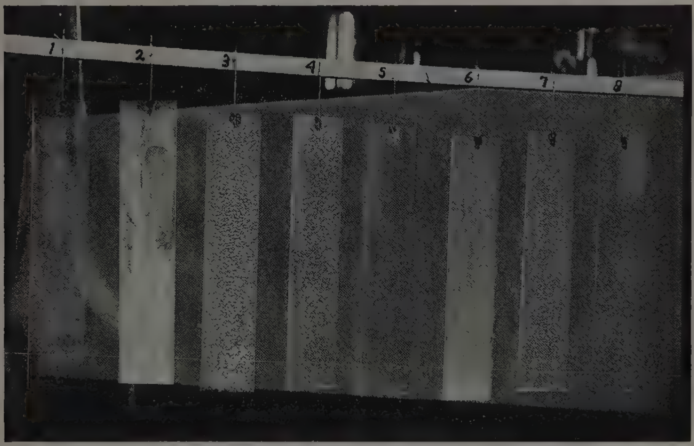

Fig. 15. Sections of glass sprayed and dusted with lead arsenate, on which freshly hatched larvae were placed.

with lead arsenate and thence transferred to unsprayed apples. Ordinary window glass was cut into sections three inches by fifteen inches in size. A piece of thread was fastened with sealing wax to the top of each section. Some of the sections were sprayed and some dusted uniformly on both sides. Tests were made of mist, coarse and film coverages with lead arsenate in concentrations of two and eight pounds to one hundred gallons. The dust was a mixture of ninety per cent sulfur and ten per cent lead arsenate, the same as used in the tests with apples. The sections were suspended over saucers of water and freshly hatched larvae placed upon them. In each case the larvae were placed near the middle of the section, half being placed on one side and half on the other. After remaining on the sections for periods

TABLE 13

RESULTS OF TESTS IN WHICH LARVAE WERE PLACED ON SPRAYED AND DUSTED SECTIONS OF GLASS AND LATER TRANSFERRED TO UNTREATED APPLES

	Type of coverage	Hours larvae remained on sections	Number of larvae placed on sections	Percentage falling off of sections	Percentage dying on sections	Number transferred to apples	Number making entrances	Number making stings	Total percentage causing injury A[1]	Total percentage causing injury B[2]
Lead arsenate, 2 lb. to 100 gal.	Mist	2	35			18	10	2	41.2	58.3
		2	50			42	21	2		
		3	50			44	23	1	48.0	54.5
		4	35			24	6	0	22.4	31.1
		4	50			37	13	0		
		Total	220	19.5	1.4	155	73	5	35.4	50.3
	Coarse	2	35			21	9	0	23.5	31.7
		2	50			42	9	2		
		3	55			49	6	3	14.3	17.6
		3	50			36	3	3		
		4	35			21	1	2	7.1	11.3
		4	50			32	2	1		
		Total	275	20.0	5.4	201	30	11	14.9	20.3
	Film	2	35			20	6	1	23.5	34.5
		2	50			38	10	3		
		3	55			49	6	3	13.3	17.3
		3	50			32	5	0		
		4	35			21	1	1	7.1	10.9
		4	50			34	1	3		
		Total	275	22.9	3.6	194	29	11	14.5	20.6
	Grand total		770	20.9	3.6	550	132	27	20.6	29.0
Lead arsenate, 8 lb. to 100 gal.	Mist	2	25			15	9	0	32.0	45.3
		2	50			38	13	2		
		3	25			22	9	0	26.7	32.6
		3	50			40	11	0		
		4	35			23	3	0	16.5	24.6
		4	50			34	11	0		
		Total	235	24.7	1.7	172	56	2	24.7	33.7
	Coarse	2	25			14	1	3	14.7	20.4
		2	50			40	5	2		
		3	25			22	2	2	10.7	13.6
		3	50			37	4	0		
		4	35			17	0	0	1.2	2.6
		4	50			22	1	0		
		Total	235	29.4	5.5	152	13	7	8.5	13.2
	Film	2	25			17	8	1	24.0	32.1
		2	50			39	6	3		
		3	25			19	4	0	10.7	16.7
		3	50			29	2	2		
		4	35			14	0	0	0.0	0.0
		4	50			20	0	0		
		Total	235	31.9	6.4	138	20	6	11.1	18.8
	Grand total		705	28.6	4.5	462	89	15	14.7	22.5
90%–10% sulfur-lead arsenate dust		2	50			37	9	2	18.0	24.0
		2	50			38	7	0		
		3	55			52	2	0	5.7	6.9
		3	50			34	2	2		
		4	35			19	0	0	0.0	0.0
		4	50			31	0	0		
		Total	290	22.1	4.5	211	20	4	8.3	11.4
Check		2	60			44	28	0	52.7	64.4
		2	50			46	30	0		
		3	55			51	18	0	42.8	46.4
		3	50			46	27	0		
		4	35			26	12	0	38.8	50.8
		4	50			39	21	0		
		Total	300	16.0	0.0	252	136	0	45.3	53.9

[1] Based on number of larvae placed on sections of glass.

[2] Based on number of larvae transferred to apples.

of two, three and four hours, the larvae were transferred to untreated apples. Subsequently, determinations were made of the number of entrances and stings on the apples.

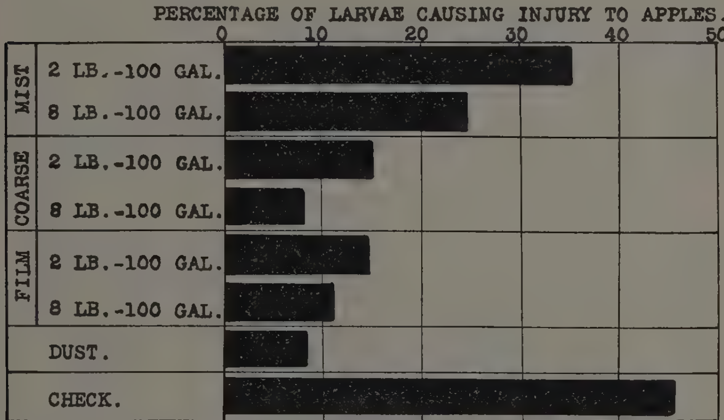

Fig. 16. Graph based on the data of table 13, indicating the extent that freshly hatched larvae were able to injure apples after crawling over sections of glass sprayed and dusted with lead arsenate.

Complete results of the tests are given in table 13 and a summary in table 14. The results are illustrated graphically in figure 16. More than twice as many larvae entered the apples from the mist coverage as from the coarse and film coverages. This inferiority of the mist coverage agrees with all other tests reported on foregoing pages. The coarse and film coverages gave about the same results.

TABLE 14

Summary of Data on Tests with Sections of Glass, Compiled from Results shown in Table 13

Type of coverage	Lead arsenate, 2 lb. to 100 gal.		Lead arsenate, 8 lb. to 100 gal.		90%-10% sulfur-lead arsenate dust		Check—untreated	
	Total injury—per cent		Total injury—per cent		Total injury—per cent		Total injury—per cent	
	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]
Mist coverage	35.4	50.3	24.7	33.7				
Coarse coverage	14.9	20.8	8.5	13.2				
Film coverage	14.5	20.6	11.1	18.8				
Dust coverage					8.3	11.4		
Check							45.3	54.8
Average	20.7	29.0	13.3	22.5	8.3	11.4	45.3	54.8

[1] Percentage of injury based on the number of larvae placed on the sections.
[2] Percentage of injury based on the number of larvae transferred from the sections to the apples.

Seven per cent more larvae became poisoned on the sections sprayed with the eight-pound concentration than with the concentration of two pounds. The explanation for this result, the author believes, is that the thick deposits of the concentration of eight pounds to one hundred gallons stimulated the larvae to bite against the poison while this thigmotactic reaction was brought into play to less extent with the thinner deposits of the lower concentration. About the same percentage of larvae became poisoned on the dusted sections as on those having the coarse coverage of lead arsenate at eight pounds to one hundred gallons of water.

CALYX SPRAY STUDIES

Limited studies were made for the purpose of obtaining information on the efficacy of lead arsenate in preventing the entrance of larvae through the calyces of apples. Yellow Bellflower apples were used in the experiments. At the time the trees were in bloom, certain branches were tagged and the blossoms sprayed individually by means of a small bulb atomizer. In order to give uniform treatment to all blossoms, the tip of the atomizer was held approximately two inches directly in front of each calyx and four full aspirations made on the atomizer. This resulted in a finely divided spray striking the calyx with force and in sufficient quantity that some of the spray ran off the sepals. In case of the mist spray, the tip of the atomizer was held six inches from the calyx and the same number of aspirations made, but the spray reached the calyx only as floating mist particles. The following treatments were made:

Lead arsenate, 2 lb. to 100 gallons of water.

(1) Full blossom, forceful spray; applied before petals had fallen.
(2) Calyx, forceful spray; applied just after all petals had fallen.
(3) Calyx, forceful spray with casein-lime spreader added at the rate of one pound to one hundred gallons of spray; applied just after all petals had fallen.
(4) Calyx, mist spray; applied just after all petals had fallen.

Lead arsenate, 4 lb. to 100 gallons of water.

(5) Calyx, forceful spray with casein-lime spreader as in No. 3; applied just after all petals had fallen.

The last week of July the apples that developed from the treated blossoms were picked and taken into the laboratory. Each apple was cut transversely into portions of one-third and two-thirds, the one-third portion being the blossom end. The cut surface of the blossom portion was placed on the bottom of a saucer and a small quantity of water placed in the saucer (fig. 17). Ten freshly hatched larvae were then

placed inside the calyx, just under the sepals. Four days later the parts were removed and cut vertically so as to divide the calyx cavities into halves. Records were then made of the injuries. After this the sepals were cut off at their bases and thrown away. By use of a sharp

Fig. 17. The blossom ends of apples placed in saucers containing a small quantity of water for calyx spray studies.

TABLE 15

RESULTS OF CALYX SPRAY TESTS IN WHICH TEN LARVAE WERE PLACED IN EACH CALYX CAVITY

Number of test	Treatment	Number of calyces	Number of entrances		Average micromilligrams of As_2O_3 per calyx cup and cavity		
			Outer cups	Inner cups	Outer cups	Inner cups	Average per calyx cavity
1	Full blossom; lead arsenate, 2 lb. to 100 gal.	5	....	....	2.4	0.8	3.2
2	Calyx; lead arsenate, 2 lb. to 100 gal.	10	....	....	6.7	2.3	8.9
3	Calyx; lead arsenate, 2 lb. to 100 gal. and spreader	21	0	1	9.5	7.0	16.5
4	Calyx; mist; lead arsenate, 2 lb. to 100 gal.	11	....	....	1.0	0.6	1.6
5	Calyx; lead arsenate, 4 lb. to 100 gal. and spreader	12	1	4	20.0	13.3	33.3

knife, each one-half calyx cavity was cut out and determinations made by the Gutzeit method of the quantity of arsenic in the outer and the inner calyx cups. The stamens were included with the outer cup.

The results of the tests are given in table 15.* The principal value of the studies is to indicate the relative effectiveness with which lead

* Unfortunately, the data on the injury in tests 1, 2, and 4, were accidentally destroyed.

arsenate is placed in the calyx cavities by different spray methods, a matter that has been widely discussed during the past quarter century. The mist spray showed less than one-fifth as much arsenic per calyx cavity as the forceful spray. Almost twice as much arsenic occurred in the calyx cavities sprayed with lead arsenate and casein-lime spreader as in those sprayed only with lead arsenate. In applying the spray without the spreader it was noticed that there was a marked tendency for the particles of spray to bound off or to collect into drops and run off without wetting the calyces. Spraying before the petals had fallen resulted in about one-third less arsenic per calyx cavity than spraying after the petals had fallen.

It is especially interesting to note that in test number 5, in which lead arsenate was used at the rate of four pounds to one hundred gallons of water, five larvae or approximately four per cent of the number transferred, entered apparently unharmed.

STUDIES ON THE BEHAVIOR OF FRESHLY HATCHED LARVAE

In order to understand the manner in which lead arsenate protects apples, it is necessary to observe the behavior of the larvae. Thigmotaxis, phototaxis and thermotaxis were the most important tropisms influencing the larvae in the studies reported in this paper.

Behavior on Unsprayed Apples

When a freshly hatched larva is placed on an apple, it crawls rapidly over the surface, apparently in search of a suitable place to make entrance. If the surface is smooth, the larva may crawl for two or three hours before making any attempt to dig into the apple. Usually after the first fifteen or twenty minutes, the rate of locomotion gradually decreases and frequent pauses may occur during which the head is thrown from side to side. In the latter movement numerous fibers are spun beneath the head. Occasionally larvae were observed to grasp these fibers with the thoracic legs and bring the tips of the mandibles into contact with the apple but seemingly without making any serious attempt to force the mandibles through the skin.

The larva exhibits a decided tendency to examine any slight eruption or other irregularity on the surface of the apple. When first placed on the apple, however, it may not pay the least attention to what may appear to the observer to be excellent places for entrance.

Manner of Effecting Entrance

If no especially favorable point of entrance is encountered, the larva finally comes to rest and spins a mat of fibers, attached to the skin of the apple, beneath its head. This mat is grasped by the thoracic legs and the main strength of the body centered on forcing the points of the mandibles through the skin. The particles of skin that are cut out appear always to be rejected. The time required for making entrance

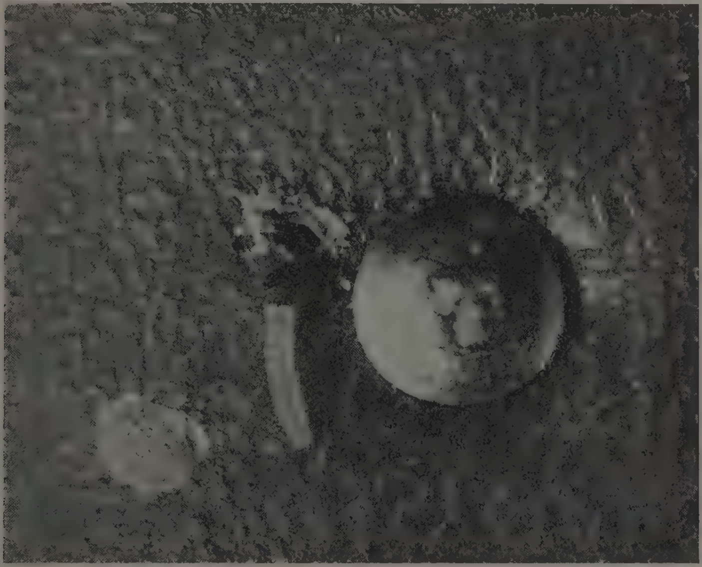

Fig. 18. Microphotograph of a newly hatched larva and an entrance which it had started. Bits of apple skin cut off by the larva are piled about the hole. On the right is the head of a pin and on the lower left the shell of a codling moth egg.

varies greatly, according to the vigor of the larva, and light and temperature. One larva that was placed in direct sunlight just after starting an entrance, excavated a burrow deep enough to receive its body in twenty-four minutes. Usually the time required ranged from one to three hours when the temperature of the laboratory was about 76° F.

The fact that the larva rejects the apple skin was noted in 1897 by Card[31] and Slingerland,[32] but its significance has been almost entirely overlooked by later investigators. Two kinds of tests were made to determine whether the larva swallows any of the skin in digging into

the apple. A small apple was given a thick coating of water-proof ink. After being suspended for a few days until the odor of the ink had disappeared, a number of larvae were placed on the apple. When a larva had burrowed the length of its body into the apple, it was removed and the digestive tract dissected out and examined for the presence of particles of ink. While in many instances the particles could be seen through the larva's body, accurate information required dissection. From the careful study of twenty-five larvae, the following data were obtained:

	Number of larvae	Per cent of larvae
Black particles of ink found in digestive tract	18	72.0
No particles of ink found in digestive tract	7	28.0

In the other test, three apples were coated with gentian violet stain, and larvae transferred and observed as in the above test. The following data were obtained:

	Number of larvae	Per cent of larvae
Stain pronounced in digestive tract	33	60.0
Stain slight in digestive tract	14	25.4
No stain in digestive tract	8	14.6

The studies indicated quite clearly that swallowing of particles of apple skin occurs incidentally as the larva digs into the apple. As previously noted herein, this has an important bearing on the efficacy of the film coverage of lead arsenate in protecting apples. If the film is thin, it might be expected that as many as fifteen per cent of the larvae will effect entrances without swallowing any poison. Since the larva must dig into the apple by use of its mandibles, it seems evident that the thicker the coating of poison is, the greater the chance that some poison will be swallowed.

Behavior on Sprayed Apples

When placed on an apple having a spotted coverage of lead arsenate, the larva exhibits a slight tendency to rest upon the deposits of poison. In doing this, mats of fiber are sometimes spun on the deposits and a number of instances were observed in which the mandibles were brought directly into contact with the poison. Some poison may at times be swallowed in this reaction. Perhaps the most marked reaction is the thigmotactic response to the thick lower edges of spray deposits. Larvae were commonly observed to place the lower margin of their heads against the raised edges of deposits and spend several seconds or a few

minutes "nosing" about. It was noticed that entrances and stings were commonly made at the edges of deposits. This is shown by the microphotograph in figure 19. Three entrances are shown, the lowest one being made directly through a deposit and the two toward the top being made at the edges of deposits. In order to obtain data on this

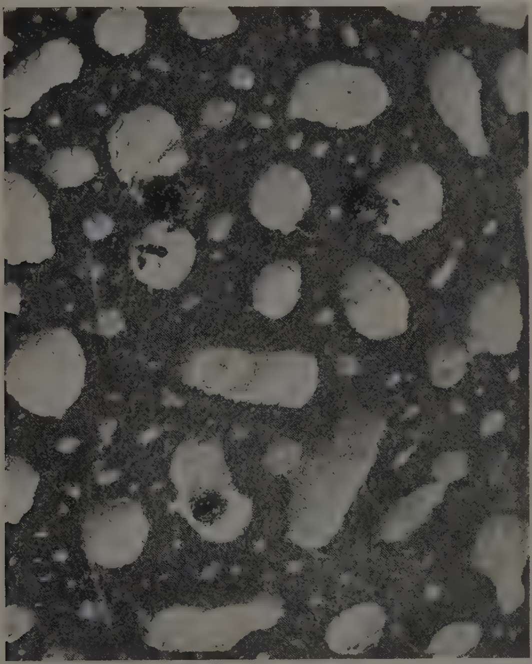

Fig. 19. Microphotograph of three entrances of freshly hatched codling moth larvae in apple with spotted coverage of lead arsenate.

question, an apple was sprayed with calcium carbonate in concentration of eight pounds to one hundred gallons of water, a coarse coverage being produced. Larvae were then transferred and after they had entered careful examination was made of the places where entrances were made. The following results were obtained:

	Number of entrances	Number of stings	Per cent of total injury
Through deposits	1	5	19.3
At edges of deposits	12	2	45.2
Between deposits	10	1	35.5

Behavior on Dusted Apples

Loose dust very decidedly interferes with the movement of larvae over apples. The greater protectiveness of the dust covering of lead arsenate, as shown by foregoing tests, apparently is due to the larvae becoming poisoned while merely crawling over the dusted surface.

Whether poisoning occurs through the particles of lead arsenate being taken into the spiracles or being swallowed, has not been definitely determined. An experiment was performed in which a small quantity of cornmeal was soaked in water-proof ink. After drying for several days, allowing the odor to disappear, the meal was ground in a mortar and the finest part separated out and dusted over an apple. Larvae were then placed on the apple and at the end of one-half hour their digestive tracts were examined for the presence of particles of cornmeal. Of twenty-five larvae examined, three revealed definite evidence of having swallowed some particles.

SUMMARY AND CONCLUSIONS

Probably no insect pest in the history of horticulture has been the subject of as much discussion and experimentation as the codling moth. During the past forty-five years investigations have dealt to a very large extent with arsenical sprays as a means of control. The extensive literature reveals many incongruous experimental data and varied beliefs. Spray experiments have been confined almost entirely to tests made under orchard conditions.

Laboratory studies with freshly hatched codling moth larvae were undertaken for the purpose of ascertaining the more basic facts relating to the efficacy of lead arsenate in protecting apples against codling moth injury.

The principal tests were made with apples taken from trees during July and August and sprayed in a technical manner in the laboratory. Four types of spray coverages were differentiated and tested: mist, coarse, overspray and film.

The spray was relatively ineffective in protecting the apples. With the concentration of two pounds of powdered lead arsenate to one hundred gallons of water, approximately one-third of the larvae entered the apples unharmed through the coarse, overspray and film coverages.

The mist coverage was very much less effective than the other coverages.

The coarse, overspray and film coverages were about equal in protectiveness at concentrations of four pounds or less of lead arsenate to one hundred gallons of water. At concentrations of more than four pounds to one hundred gallons the film coverage gave greater protection than the other coverages.

Increasing the concentration, in all coverages, resulted in decidedly decreasing the percentage of larvae effecting entrances.

At equal amounts of arsenious oxide per square centimeter of apple surface, approximately one-third as many larvae entered through the film coverage as through the coarse and overspray coverages.

In all coverages, protectiveness varied directly with the amount of arsenious oxide per square centimeter of apple surface.

Apples heavily oversprayed and then lightly shaken to cause the large drops of spray to run off were injured very much more than oversprayed apples that were not shaken.

The percentage of larvae making stings increased as the percentage effecting entrances decreased except that at the concentration of sixteen pounds of lead arsenate to one hundred gallons of water there was a decrease both in stings and entrances.

A loose, light covering of 90%–10% sulfur-lead arsenate dust was much more effective in protecting the apples than lead arsenate spray in concentration of two pounds to one hundred gallons.

Experiments in which larvae were placed on sprayed and dusted sections of glass and later transferred to unsprayed apples revealed that many larvae became poisoned while crawling over the sprayed and dusted glass; that the mist coverage was decidedly inferior to the others in killing efficiency; that the greater the concentration of spray and the more lead arsenate on the glass, the more larvae killed; and that the loose covering of sulfur-lead arsenate dust was high in effectiveness.

Experiments in which larvae were placed on the leaves of cuttings from the growing ends of apple branches, to which apples were artificially attached, revealed that the spray on the leaves and bark was about equal to the spray on the apples in destroying the larvae and that the percentage of larvae poisoned varied directly with the concentration of the spray.

The thick lower edges of spray deposits stimulate the thigmotactic reactions of freshly hatched larvae.

Tests in which larvae were placed on apples coated with water-proof ink and on apples covered with gentian violet stain indicated that some larvae may reject the skin to such extent as not to swallow any in digging into the apple.

Thickness of film is the most important factor relating to the protectiveness of the film coverage.

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* The manuscript for this paper was prepared in the spring of 1925. These references have since been appended because they include discussions of the experimental data with special reference to the application of the data to the practical control of the codling moth in apple orchards.